

Quantifying Green Hydrogen Yields from Photovoltaic Systems in Arid Climates: Application to Ouargla, Algeria

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ABSTRACT

Algeria, particularly its southern regions such as Ouargla, offers exceptional solar energy potential, with annual Global Horizontal Irradiance (GHI) exceeding 2,000 kWh/m². This study evaluates the technical feasibility of green hydrogen production in Ouargla using Photovoltaic (PV) energy and a simplified modeling approach based on monthly satellite-derived solar data. A standalone 1000 m² PV system with 20% efficiency was modeled, coupled with a Proton Exchange Membrane (PEM) electrolyzer operating at 65% efficiency. Key performance indicators, including monthly PV output, hydrogen production, electrolyzer utilization, and system efficiency, were calculated using standardized assumptions. The results indicate strong seasonal variation, with hydrogen yields peaking during summer months and total annual output reaching approximately 7,864 kg. These findings are consistent with earlier experimental and modeling studies conducted in similar arid environments and confirm Ouargla's suitability for pre-industrial green hydrogen initiatives. The study offers a replicable framework for early-stage project assessment and supports national strategies for energy diversification and low-carbon development in high-insolation regions.

Keywords-green hydrogen; solar energy; photovoltaic system; electrolyzer utilisation; PEM electrolyzer

I. INTRODUCTION

The global transition toward low-carbon and sustainable energy systems has positioned green hydrogen as a cornerstone of/has rendered green hydrogen significant for future decarbonization strategies [1]. Produced from renewable resources, such as solar and wind power, green hydrogen provides a clean, flexible, and efficient solution for long-term energy storage and balancing the intermittency of renewable energy generation [2]. The main opportunities associated with the development of hydrogen roadmaps include the creation of new industrial sectors, the reduction of greenhouse gas emissions, and the reinforcement of energy security through the diversification of energy sources. However, several challenges persist, including the high cost of electrolysis technologies, the

limited availability of large-scale storage and transport infrastructure, and the need for coherent policy and regulatory frameworks. The large-scale deployment of green hydrogen will depend on integrated efforts combining technological innovation, supportive financial mechanisms, and international collaboration. Environmental and economic assessments demonstrate that solar hydrogen production is a sustainable and viable solution. From an environmental perspective, solar-powered electrolysis significantly reduces greenhouse gas emissions and minimizes ecological impact compared with fossil-based hydrogen production [3]. Economically, the competitiveness of solar hydrogen depends largely on electricity costs and electrolyzer efficiency; however, the continuous decline in PV module prices and advances in electrolyzer performance have greatly improved its feasibility.

In regions with high solar irradiance, solar hydrogen can provide a reliable and cost-effective solution for industrial decarbonization and integration into national clean energy strategies [4].

Hybrid systems that combine solar [5] and wind [6] energy offer an optimized approach for continuous hydrogen generation [7]. The complementarity between daytime solar irradiance and nighttime wind regimes enhances the stability of energy supply and increases the operational efficiency of electrolyzers. Technically, such hybrid configurations improve the capacity factor and reduce production variability; economically, they lower the Levelized Cost of Hydrogen (LCOH) through better resource utilization. In addition, their environmental benefits include a minimal carbon footprint and efficient land use. Overall, hybrid, solar, and wind hydrogen systems represent a robust, scalable, and regionally adaptable solution for sustainable hydrogen production and the development of future clean energy infrastructures [8].

The understanding and modeling of solar-based green hydrogen systems, particularly in North Africa and arid regions, have been advanced. In southern Algeria, authors in [9] studied a hydrogen-based hybrid system combining PV, diesel, fuel cell, and pumped hydro storage technologies. The system was found to optimally electrify remote areas, achieving high reliability, a largely renewable energy fraction, and significant CO₂ reduction. In [10], a dynamic model of PEM electrolyzers was presented using MATLAB and Simscape to optimize hydrogen output under hybrid PV and wind configurations [10]. In [11], a complete microgrid for off-grid electrification was evaluated, combining PV panels, wind turbines, batteries, an electrolyzer, a hydrogen tank, and a fuel cell, demonstrating the system's adaptability to isolated regions. Authors in [12] evaluated a 1 MW on-grid hybrid PV and wind system that produced approximately 16 tons of hydrogen per year, demonstrating the feasibility of grid-integrated solutions. The off-grid PV and wind hybrid systems with integrated hydrogen production in Algeria were analyzed, exhibiting region-dependent techno-economic feasibility, with costs highly sensitive to solar and wind resources and capital investment [13]. These systems could provide a sustainable solution for decentralized electricity and hydrogen supply.

On the experimental front, authors in [14] evaluated the feasibility and regional potential of green hydrogen production in Algeria. Their study highlighted both desert and northern regions using advanced simulation tools, such as HOMER Pro, to compare PV productivity and hydrogen yields. They emphasized sustainable water management, innovative seawater and wastewater utilization, and strategic proximity to European markets, providing a holistic approach to maximizing the technical, economic, and environmental benefits of Algeria's green hydrogen transition. A record 28% solar-to-hydrogen conversion efficiency was demonstrated using an advanced PV-alkaline system in Saudi Arabia, and a detailed techno-economic assessment was provided, making it a benchmark for performance [15]. These studies highlight the technical maturity, environmental potential, and regional readiness for scaling up green hydrogen in solar-rich environments.

In the strategic and policy context, the opportunities and challenges associated with Algeria's green hydrogen roadmap have been explored [16]. Previous works have conducted environmental and economic evaluations of solar hydrogen feasibility, while others have highlighted Algeria's strategic position within the broader North African hydrogen export framework, combining strong technological potential with geopolitical relevance [14, 17-20]. The geographical, technical, economic, and environmental potential of wind-based hydrogen production in the country have been assessed [21, 22].

This study aims to quantitatively assess the green hydrogen production potential of Ouargla using PV energy under arid climate conditions. The specific objectives are:

1. To analyze the monthly solar resource availability in Ouargla using satellite-derived data.
2. To estimate PV energy production using simplified system assumptions.
3. To quantify monthly and annual green hydrogen yields using a PEM electrolyzer model.
4. To evaluate seasonal trends and system performance indicators relevant to early-stage project planning.

Despite Algeria's exceptional solar potential, particularly in southern regions such as Ouargla, there is a lack of localized, data-driven assessments quantifying solar-to-hydrogen conversion performance. Most existing studies focus on national-scale analyses or complex hybrid systems, whereas simplified and replicable models suitable for early-stage project evaluation at the regional level are limited.

This study presents a quantitative, data-driven assessment of the green hydrogen production potential in Ouargla, Algeria. The region is characterized by exceptional solar irradiance but has received limited scientific investigation. Using real solar radiation data and a simplified, transparent modeling approach, the study provides localized insights into solar-to-hydrogen conversion performance, captures seasonal variability, and establishes a baseline for future techno-economic and environmental optimization studies. In addition to its scientific contribution, the work has strong practical and policy relevance. It supports strategic energy transition planning, guides early-stage project development through a replicable evaluation framework, and underscores the potential of high-insolation desert regions, such as Ouargla, to attract sustainable investments in green hydrogen infrastructure with efficient land utilization.

II. METHODOLOGY

A. Data Collection

To evaluate the green hydrogen production potential in Ouargla, Algeria, this study uses a combination of satellite-derived climatological data and standardized system design assumptions. Specifically, monthly GHI data for Ouargla were obtained from the NASA Prediction Of Worldwide Energy Resource (POWER) database, a widely used source in renewable energy modeling due to its long-term accuracy and

accessibility. The modeled PV system assumes a surface area of 1000 m² and a conversion efficiency of 20%, aligning with assumptions used in studies for desert climates. These parameters were selected to reflect both the technical feasibility and scalability of pre-industrial pilot systems. In this study, the monthly hydrogen output and system efficiency trends were estimated, providing valuable site-specific insights for policymakers and developers during the early planning stages.

The process begins with the acquisition of solar data, which are subsequently converted into PV energy. This energy serves as input to an electrolyzer model for hydrogen production. The produced hydrogen is then evaluated using relevant performance indicators to assess the overall system efficiency and effectiveness, as detailed below.

1) Solar Resource and Meteorological Data

Monthly average values of GHI and ambient temperature were collected using open-access satellite databases. The primary sources considered are:

- **NASA POWER:** Provides long-term climatological data at daily and monthly resolutions. The GHI values extracted correspond to the coordinates of Ouargla (approximately 31.95°N, 5.33°E), representing typical solar availability in the region [23].
- **Photovoltaic Geographical Information System (PVGIS):** Developed by the European Commission's Joint Research Centre, PVGIS provides validated solar radiation and temperature datasets suitable for PV performance modeling in North Africa [24].

The dataset presented in Table I provides monthly values significant for estimating the green hydrogen production potential in Ouargla, Algeria, based on PV solar energy. It includes four key variables for each month: GHI, PV energy output, hydrogen output, and system efficiency.

TABLE I. MONTHLY GHI AND SYSTEM EFFICIENCY FOR THE PV-ELECTROLYZER SETUP IN OUARGLA

Month	GHI (kWh/m ²)	PV energy output (kWh)	Hydrogen output (kg)	System efficiency (%)
January	165	33,000	429	65
February	180	36,000	468	65
March	215	43,000	559	65
April	240	48,000	624	65
May	260	52,000	676	65
June	275	55,000	715	65
July	280	56,000	728	65
August	260	52,000	676	65
September	230	46,000	598	65
October	200	40,000	520	65
November	175	35,000	455	65
December	160	32,000	416	65

GHI represents the amount of solar radiation received on a flat surface per unit area and is expressed in kWh/m². The monthly GHI values used in this study reflect average conditions and were used as inputs to calculate the PV energy output.

The modeled system includes a grid-independent solar-powered hydrogen production unit consisting of:

2) PV Array

- Surface area of 1000 m² (representing a medium-scale solar field).
- Conversion efficiency of 20% (accounting for module, inverter, and system losses).
- The PV system was assumed to operate under standard conditions without storage or grid feed-in.

3) Electrolyzer Unit

- A PEM electrolyzer was selected because of its high responsiveness to intermittent solar input and compact design.
- Efficiency of 65% was assumed, indicating that 65% of the input electrical energy is effectively converted into hydrogen (higher heating value basis).
- Energy requirement of 50 kWh/kg of hydrogen produced (based on literature-reported values for PEM systems).

The PV energy output is calculated by:

$$E_{PV} = GHI \times PV_{area} \times PV_{efficiency} \quad (1)$$

where GHI is given in kWh/m², PV_{area} is the total surface area of the solar panels (1000 m²), and PV_{efficiency} is the overall energy conversion efficiency (assumed to be 20%). This calculation yields the amount of electrical energy (in kWh) generated by the PV system each month.

System efficiency, expressed as a percentage, is the overall efficiency of converting solar irradiance into hydrogen energy. In this model, it is held constant based on the assumed PV and electrolyzer performance. More complex models may vary this with temperature or load fluctuations, but for early-stage feasibility studies, fixed values provide a useful baseline.

This electrical energy is then used to produce hydrogen via electrolysis. The electrical energy generated by the PV system is supplied directly to the PEM electrolyzer. Due to the intermittent nature of solar power, the electrolyzer operates dynamically following the available PV output. The conversion process accounts for electrochemical losses, auxiliary consumption, and stack efficiency, which are collectively represented through an assumed average electrolyzer efficiency of 65%. This simplified representation is commonly used in early-stage feasibility studies to estimate hydrogen yields while maintaining model transparency. The amount of hydrogen produced is calculated by:

$$H_2 \text{ (kg)} = E_{PV} \times \frac{\lambda_{el}}{E_{req}} \quad (2)$$

where λ_{el} is the electrolyzer efficiency (65% assumed), and E_{req} is the energy needed to produce 1 kg of hydrogen (typically ~50 kWh/kg H₂ for PEM electrolyzers).

This gives the monthly hydrogen output in kg. The hydrogen output closely follows the PV output and, thus, the solar irradiation profile.

These data can be used as:

- Feasibility studies: The hydrogen output can be used to estimate the amount of green hydrogen that can be produced on a monthly or yearly basis, helping to determine whether a project is viable for local or export needs.
- System sizing: If a target hydrogen demand is known, these data can help size the PV field and electrolyzer unit accordingly.
- Seasonal planning: Since solar availability varies monthly, these data help in planning hydrogen storage, backup systems, or hybrid energy inputs for a stable supply.
- Techno-economic models: The energy production and hydrogen yield data feed directly into LCOH and Net Present Value (NPV) calculations.
- Environmental assessment: Determining the amount of hydrogen produced enables the estimation of avoided CO₂ emissions compared to conventional (gray) hydrogen production.

B. PV Energy Output Model

Equation (1) was used throughout the analysis to estimate monthly PV energy output. The monthly values were computed and utilized as input for the hydrogen production model.

C. Hydrogen Production Model

Assuming a 65% efficient electrolyzer and an energy requirement of 50 kWh per kg of H₂, the monthly hydrogen output was calculated using:

$$H_2 = E_{PV} \times \frac{\text{Efficiency}}{50} \quad (3)$$

III. RESULTS AND DISCUSSION

This study evaluates the monthly performance of a solar-powered green hydrogen production system in Ouargla, Algeria, using satellite-derived solar irradiance data and simplified modeling assumptions. The results highlight strong seasonal trends in energy generation and hydrogen yield, consistent with the desert region's solar resource profile.

Figure 1 shows the monthly PV energy output, revealing that the electrical generation from the PV array follows a typical solar radiation pattern. The highest energy output occurs in July (56,000 kWh), while the lowest is in December (32,000 kWh). This variation reflects the shift in GHI throughout the year, which ranges from 160 kWh/m² in December to 280 kWh/m² in July.

Figure 2 illustrates the monthly hydrogen output, which is directly proportional to the available PV energy. Hydrogen production ranged from 416 kg in December to 728 kg in July, reflecting the linear relationship between solar input and electrolyzer performance. This confirms that solar radiation is the dominant factor influencing seasonal hydrogen availability.

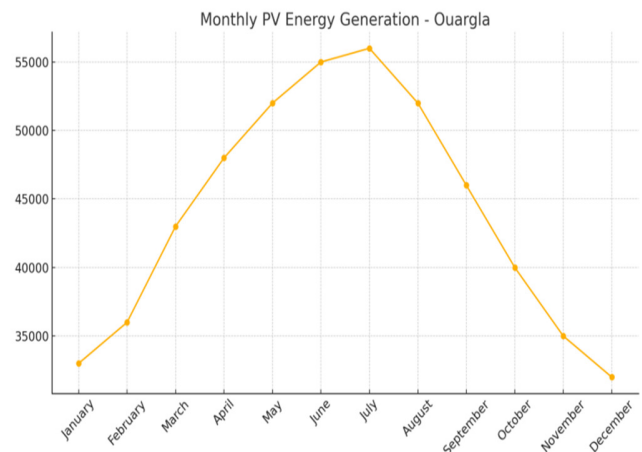


Fig. 1. Monthly PV energy output in Ouargla.

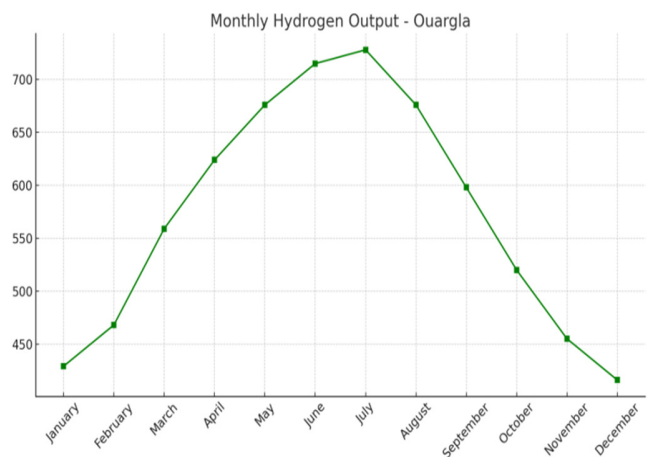


Fig. 2. Monthly hydrogen output in Ouargla.

Figure 3 depicts the electrolyzer utilization factor, showing peak utilization during summer months and a dip during winter. For example, in July, with a GHI of 280 kWh/m², the PV energy output is calculated as:

$$E_{PV} = 280 \times 1000 \times 0.20 = 56000 \text{ kWh} \quad (4)$$

This energy results in hydrogen production estimated using:

$$H_2 = \frac{56000 \times 0.65}{50} = 728 \text{ kg}$$

Although the electrolyzer's nominal efficiency is held constant at 65%, its operational intensity is dictated by the variable power input from the PV system. Higher utilization translates into more productive months (June–August), enhancing economic viability and reducing hydrogen production costs per kg. These findings support the results reported in a dynamic simulation study under similar climates [10].

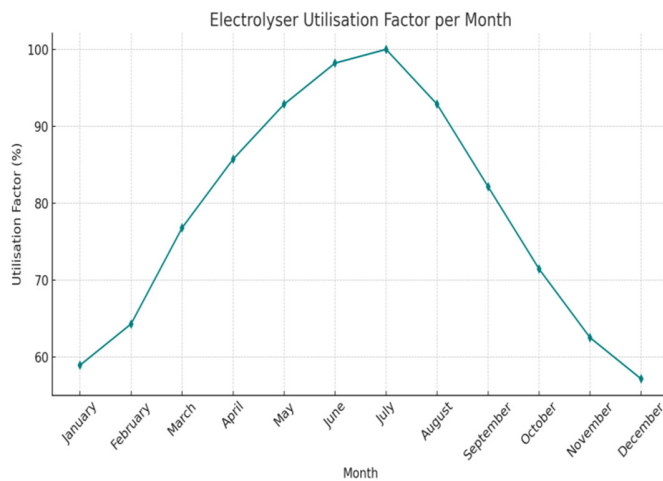


Fig. 3. Electrolyzer utilization factor.

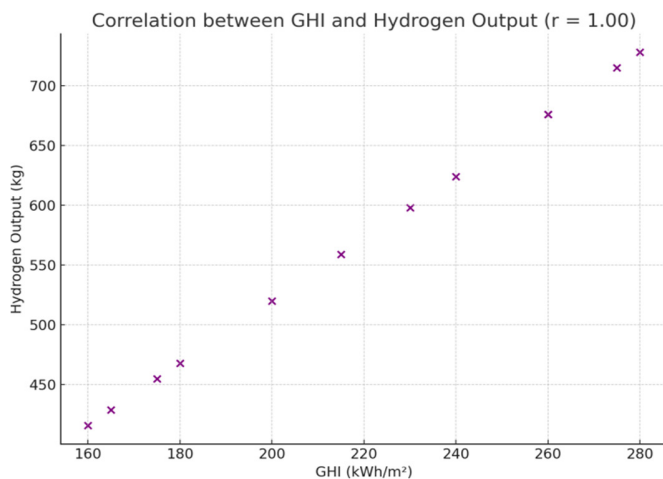


Fig. 4. GHI versus hydrogen correlation.

Figure 4 shows that the correlation between GHI and hydrogen output is nearly perfectly linear, confirming the strong dependency of hydrogen production on solar irradiance under fixed system parameters. This validates the use of GHI as a primary input in feasibility assessments and site selection.

Finally, Figure 5 demonstrates the efficiency of the system, which remains constant owing to the model assumptions (20% PV conversion and 65% electrolyzer efficiency). While real-world conditions might introduce slight variations due to ambient temperature or component degradation, this fixed efficiency provides a robust baseline for early-stage planning and techno-economic analyses. Figure 5 serves as a baseline assumption for more advanced models and allows stakeholders to easily estimate output and costs under given environmental conditions. Overall, the results indicate that Ouargla's high solar potential enables year-round hydrogen production, with optimal yields during summer.

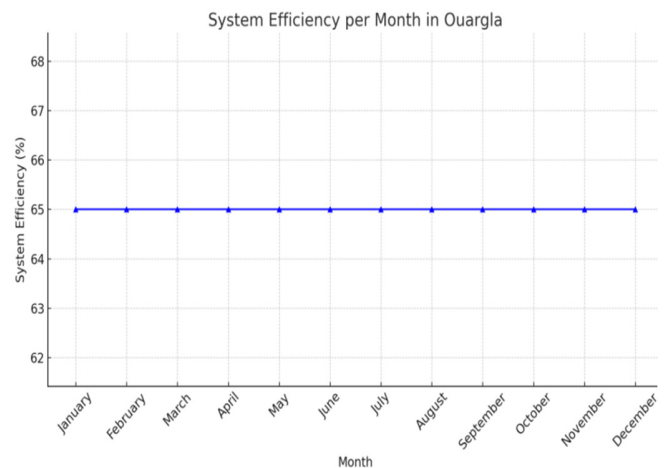


Fig. 5. System efficiency.

The findings support the city's inclusion in national hydrogen planning and demonstrate its suitability for medium-scale demonstration projects. This simplified model, grounded in real satellite data, offers a replicable method for assessing hydrogen potential in other high-irradiation zones across Algeria and the wider region.

IV. CONCLUSIONS

This study quantitatively evaluated the green hydrogen production potential of Ouargla, Algeria, a region characterized by very high solar availability (annual Global Horizontal Irradiance (GHI) > 2,000 kWh/m²). Using monthly satellite data from NASA POWER and a simplified modeling approach, a 1000 m² Photovoltaic (PV) system (20% efficiency) coupled with a Proton Exchange Membrane (PEM) electrolyzer (65% efficiency) was assessed. The estimated hydrogen production ranged from 416 kg in winter months to 728 kg in summer, demonstrating a strong seasonal dependence driven by solar irradiation.

The results confirm that Ouargla is technically well-suited for solar-based green hydrogen production, benefiting from high solar potential and favorable land availability. The proposed modeling framework is simple, transparent, and replicable, making it suitable for early-stage feasibility studies, system sizing, and preliminary planning.

Future work should focus on validating these findings through pilot-scale installations, extending the analysis to multi-megawatt systems, and incorporating storage, hybrid renewable inputs, and environmental impact assessments to support large-scale deployment within Algeria's national hydrogen strategy.

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